Design and Optimal Configuration of Full-Duplex Wi-Fi Networks Using Hybrid Mac Protocol

[1]Mokara Harish, [2]Prof. Kuda Nageswara Rao
[1]M.tech. Student, [2]Professor
Department of Computer Science and System Engineering,
Andhra University College of Engineering (A), Visakhapatnam, AP, India.

Abstract: Wireless sensor network are the collection of individual nodes which are able to interact with physical environment statically or dynamically by sensing or controlling physical parameter. The design of an energy efficient Medium Access efficient Control (MAC) protocol is one of the major issues in Wireless Sensor Networks (WSN). Most of these protocols take into account the energy efficiency as a main objective. There is much more innovative work should be done at the MAC layer to address the hard unsolved problems. Methods/Statistical Analysis: Wireless sensor network become a prominent in many applications like habitat, infrastructure and industrial automation. In this paper, we first outline and discuss the specific requirements and design trade-offs of a typical wireless sensor MAC protocol by describing the properties of WSN that affect the design of MAC layer protocols. Then, a typical collection of wireless sensor MAC protocols presented in the literature are surveyed, classified, and described emphasizing their advantages and disadvantages whenever possible. Findings: In this paper we study some characteristics of WSN that are important for the design of MAC layer protocols and give a brief introduction of some MAC protocols with reference to energy efficiency for WSN. In accordance with channel access policies, MAC protocols are classified into four types, which are cross layer protocols, TDMA-based, contention-based and hybrid. For the collection of recent wireless sensor real-time MAC protocols emphasizing their advantages and disadvantages whenever possible. One of the major constraints in Wireless Sensor Networks (WSNs) is power consumption. In recent years, a lot of efforts have been put into the design of Medium Access. Control (MAC) protocols for WSN, in order to reduce energy consumption and enhance the network's lifetime. Recently, owing to the advances in the self interference (SI) cancellation technology, the in-band full-duplex (FD) capability has been demonstrated at Wi-Fi range. However, the simultaneous uplink (UL) and downlink (DL) transmission may lead to inter-user interference (IUI) and result in decoding failure. Spectrum efficiency should also be considered in the construction process of the FD transmission. In this paper, we propose a hybrid half-duplex (HD)/FD MAC protocol based on a two-fold RTS/CTS contention resolution mechanism, in order to fully exploit the channel access opportunities provided by the simultaneous UL and DL transmissions. The noteworthy features of the proposed protocol lie in the following two aspects. First, the protocol provides the flexibility for the AP to decide the probability of constructing FD transmission.

***Index Terms* – Energy Efficiency, Medium Access Control Protocol, Wireless Sensor Network, FD, MACs.**

I. INTRODUCTION

In-band full-duplex (FD) communication has attracted great attention as a promising solution to increase the spectral efficiency in wireless communications. Compared to the traditional half-duplex (HD) systems, it allows users transmitting and receiving data signals simultaneously in the same band, potentially doubling the link data rate with no extra bandwidth extension. One of the key implementation issues of FD transmission is how to reduce the self-interference (SI), which is generated by the transmitter of the device to its own receiver. Fortunately, with recent advancements, SI can be canceled close to the level of the noise floor, making FD applicable to the current wireless network infrastructure such as Wi-Fi and cellular networks . For a Wi-Fi network consisting of one FD AP and multiple FD users, once a user accesses the channel, it constructs an UL/DL transmission. In the meantime, the FD AP can support a second transmission in the other link. Due to the FD capability, the user in the second transmission can be either the same user involved in the constructed transmission or another. However, in the latter case, the simultaneous UL and DL transmissions incur inter-user interference (IUI), which needs to be limited to a certain level. Therefore, protocol adaptations are required in the MAC layer, in order to construct FD transmission while controlling the IUI.

Communication in Wireless Sensor Networks is divided into several layers. Medium Access Control (MAC) layers protocol tries to avoid collisions by not allowing two interfering nodes to transmit at the same time. This will enables for the successful operation of the network. The main design goal of a typical MAC protocols is to provide high throughput and QoS. On the other hand, wireless sensor MAC protocol gives higher priority to minimize energy consumption than QoS requirements. Energy gets wasted in traditional MAC layer protocols due to idle listening, collision, protocol overhead, and overhearing. There are some MAC protocols that have been especially developed for wireless sensor networks. Typical examples include S-MAC, T-MAC, and D-MAC, etc. To maximize the battery life-time, sensor networks MAC protocols implement the variation of active/sleep Mechanism.

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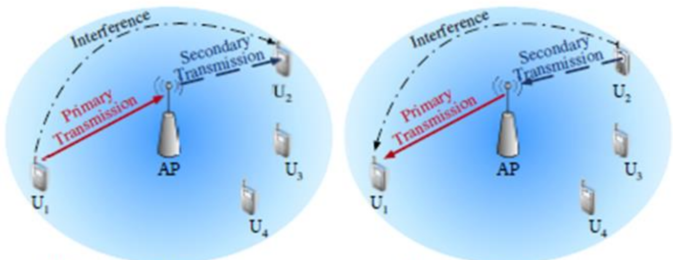
II. BACKGROUND TECHNOLOGY

This section deals with background techniques such as WSN, secure routing, challenges, Agent technology.

A. Wireless Sensor Networks (WSN) - WSN consists of sensors that are randomly distributed in an ad hoc manner. The sensor nodes sense some physical phenomenon and then the gathered information is processed. Although deployed in an ad hoc manner it needed to be self-organized and self-healing.WSN provides a bridge between the physical and virtual worlds. The

Sensor has limited sensing regions, processing power and energy. Each node of the sensor network consists of four subsystems: the sensor subsystem senses the environment, the processing subsystem performs computations on the sensed data, and the communication subsystem is responsible for message exchange with neighbor sensor nodes and power unit. A Sensor network is designed based on low node cost, low power consumption, self-configurable, scalability, adaptability, reliability, fault-tolerant, QOS, support, and security.

Energy efficiency is more important in a sensor network to ensure network performance and prolong the network lifetime. The main reason for waste of energy are ideal listening, collision, overhearing, control overhead, in medium access unlike MAC protocols, WSN schemes must allow sleep modes during radio inactivity to maximize energy efficiency. Two main classes of protocols are contention-based and contention-free. Routing in wireless sensor networks can be made robust and efficiency by incorporating different types of local information such as link quality, link distance, residual energy, and position information. Overhead includes the processing time, storage, memory consumption for a process.



UL-Primary FD Transmission DL-Primary FD Transmission

B. Security Issues in WSN - Wireless sensor networks are vulnerable to security attacks due to the broadcast nature of the wireless transmission medium. The attacks are broadly classified into two categories as active and passive attacks [2]. The monitoring and listening of communication channels by unauthorized attackers are known as passive attacks. Some of the attacks are monitor and eavesdropping, traffic analysis. The unauthorized attacker's monitors, listen and modify the data in a channel are known as active attacks. The active attacks are attacks on the information in transit, selective forwarding, black hole, and sinkhole, hello flood attacks and denial of services. These attacks are the significance of malicious nodes in wireless networks.

Monitor and eavesdropping:- Eavesdropping is secretly listening to the private conversation. The eavesdropping attack is a serious security threat to WSN. In this malicious node detect the information by listening to the message transmission in the wireless medium. And also malicious node steals the information by sending queries to transmitters by disguising themselves as friendly nodes. This attack is also known as a confidentiality attack.

Selective forwarding: - A malicious node can selectively drop only some packets. This dropping of node increases when it is combined with sinkhole or acknowledgment spoofing. The attack can be used to make a denial of service attack targeted to a particular node. In this, the malicious node will behave like a black hole and refuses to forward the packet [5].

C. Challenges - The Wireless medium is less secure because it's broadcast nature makes eavesdropping simple. The Wireless medium allows an attacker to easily intercept valid packets and easily inject malicious ones. Adhoc nature of sensor networks means no structure can be statically defined. Nodes may fail or be replace the network that must support self-configuration. Sensor nodes are deployed in a hostile environment; it faces the possibility of destruction or capture by the attackers. Providing security in WSN is even more difficult in MANETS due to the resource limitation of sensor nodes and security concerns remain a serious impediment to the widespread adaptation of these WSNs [4]. The highly hostile environment represents serious challenges for security researches. The Secure model should use battery life efficiently. WSN goals [3] include confidentiality, Integrity, Data origin authentication, Access control, Availability. It has to design against the attack such as eavesdropping, fabrication, injection, modification, node capturing.

Characteristics of Energy Efficient MAC Protocol

Energy efficiency - Since the WSN has battery constrained sensor nodes they cannot spend their energy to transmit and receive many control packets. Thus the MAC protocol should be designed such that it consumes Energy efficiently to support network lifetime.

Scalability and Adaptability - WSN protocol should be adaptable to changes in network size, density of node and topology since some nodes may stop functioning due to battery drain or link error or any other environmental problems.

Latency - Latency gives network speed. In processing of network data several kinds of delays typically sustain. In a network, small delay times considered as low latency network connection. Whereas a high latency connection experience from long delays.

Throughput - Amount of data which is able to flow throughout in a network refers to the network throughput. Throughput of the system should be high.

Bandwidth utilization - Data rate in a networking is known as bandwidth. We can't restrict speed of a network by only the network bandwidth. Network should support higher bandwidth utilization.

Fairness among sensor nodes - Fair distribution of resources in a network is determined by fairness. It is an important characteristic to take resources for communication between the nodes in a network like cluster head selection in a cluster.

III. WSN Energy Efficient MAC Protocol

In WSN many or wide range of energy efficient MAC protocols are present in the literature some of them are discussed in this paper with their essential properties. We classified these MAC protocol into four categories.

3.1 Contention based MAC Protocol

Basic approach of contention based MAC protocols are Carrier Sense Multiple Access (CSMA) and Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA). To obtain wireless channel for sending data on network MAC protocol contend with each other to get wireless channel. The channel is accessed randomly so there is no need of coordination. When the chance of collision decreases in any network than it increases performance of network. Chance of collision is decreased if a station sense the medium before trying to use it by this approach the possibility of collision is reduced. If the channel is free we can send data on the channel but if channel is not free it will wait for random amount of time. The principle of CSMA is "sense before transmit".

CSMA/CA avoids the collision using three strategies: The Interface Space (IFS), the contention window and acknowledgement. Advantage of these MAC protocol is to increase scalability and adaptability. Under this category these protocols T-MAC, S-MAC, U-MAC are defined

3.2 Sensor-MAC

S-MAC2 was based on IEEE 802.11. The function of S-MAC is to save energy. In S-MAC we divide time into frames. S-MAC protocol follows the method of periodic sleep – listen schedules. S-MAC has two stages, sleep stage and wake-up stage. Neighboring nodes setup a common sleep schedule from virtual cluster. When two neighboring node present in two different virtual clusters they will wake-up in a listen period of these two clusters which gives result in more energy consumption by idle listening and overhearing.

3.3 Timeout-MAC

Bad results of S-MAC protocol are improved by T-MAC2. It reduces energy consumption on idle listening. It uses concept of adaptive duty cycle in which messages are transmitted in different length bursts and the lengths bursts is determined dynamically. S-MAC protocol, in their time-frame has two types of periods which are active and sleep periods. In a specific time period Ta if there is no activity occurs than active period ends. The time-frame Ta represents the smallest listening time.

3.4 Ultra Wide Band MAC

U-Mac3 is use to reduce energy consumption for wireless sensor network. It uses concept of SMAC protocol by which there are three improvements in this protocol. For example selective sleeping after broadcast, various dutycycles, and utilization based tuning of duty-cycle.

3.5 TDMA based MAC

Time division multiple access is channel access method for shared medium network. In this method it is defined that the channel is dividing into time slots which is share among simultaneous users. In fixed TDMA the time slots are assigning to each terminal permanently. This result in a simple implementation but the time slot is wastage if there is no data to send. In dynamic TDMA when there is request by a terminal, time slots are assigned by central station. To implement this, a separate signaling slot is mandatory to broadcast request for slots. TDMA methods are based on scheduling in which an inherent collision-free scheme is used for transmit or receive data messages to each and every node but as compared with contention-based MAC, time slots are uniquely assigned. TDMA has an important advantage is that clashing between adjacent node is avoided. By this collision is avoided, so energy wastage due to collision is reduced. TDMA can also solve the problem of hidden terminal without using of additional data message overhead because in TDMA neighboring nodes transmit at different time slots. TDMA-based MAC protocols are μ-MAC,

3.6 μ-MAC

High sleep ratios are obtained by μ-MAC5 which is retaining the message reliability and latency. It is based on a schedule-based approach by which shared medium is accessed, which is predicted by behavior of traffic. Single time-slotted channel is used in μ-MAC protocol. Operations of this protocol alternate between a contention-free period and contention period.

IV. LITERATURE SURVEY

M. Chung, M. S. Sim, J. Kim, D. K. Kim, and C. B. Chae,
"Prototyping real-time full duplex radios,"

In this article, we present a real-time full duplex radio system for 5G wireless networks. Full duplex radios are capable of opening new possibilities in contexts of high traffic demand where there are limited radio resources. A critical issue, however, in implementing full duplex radios in real wireless environments is being able to cancel self-interference. To overcome the self interference challenge, we prototype our design on a software-defined radio platform. This design combines a dual-polarization antenna-based analog part with a digital self-interference canceler that operates in real time. Prototype test results confirm that the proposed full duplex system achieves about 1.9 times higher throughput than a half duplex system. This article concludes with a discussion of implementation challenges that remain for researchers seeking the most viable solution for full duplex communications.

A. Sabharwal, P. Schniter, D. Guo, D. W. Bliss, S. Rangarajan, and R. Wichman,
"In-band full-duplex wireless: challenges and opportunities,"

In-band full-duplex (IBFD) operation has emerged as an attractive solution for increasing the throughput of wireless communication systems and networks. With IBFD, a wireless terminal is allowed to transmit and receive simultaneously in the same frequency band. This tutorial paper reviews the main concepts of IBFD wireless. One of the biggest practical impediments to IBFD operation is the presence of self-interference, i.e., the interference that the modem's transmitter causes to its own receiver. This tutorial surveys a wide range of IBFD self-interference mitigation techniques. Also discussed are numerous other research challenges and opportunities in the design and analysis of IBFD wireless systems.

D. Korpi, J. Tamminen, M. Turunen, T. Huusari, Y. Choi, L. Anttila, S. Talwar, and M. Valkama,
"Full-duplex mobile device: pushing the limits,"

In this article, we address the challenges of transmitter-receiver isolation in mobile full-duplex devices, building on shared-antenna-based transceiver architecture. First, self-adaptive analog RF cancellation circuitry is required, since the ability to track time-varying self-interference coupling characteristics is of utmost importance in mobile devices. In addition, novel adaptive nonlinear DSP methods are also required for final self-interference suppression at digital baseband, since mobile-scale devices typically operate under highly nonlinear low-cost RF components. In addition to describing the above kind of advanced circuit and signal processing solutions, comprehensive RF measurement results from a complete demonstrator implementation are also provided, evidencing beyond 40 dB of active RF cancellation over an 80 MHz waveform bandwidth with a highly nonlinear transmitter power amplifier. Measured examples also demonstrate the good self-healing characteristics of the developed control loop against fast changes in the coupling channel. Furthermore, when complemented by nonlinear digital cancellation processing, the residual self-interference level is pushed down to the noise floor of the demonstration system, despite the harsh nonlinear nature of the self-interference. These findings indicate that deploying the full-duplex principle can indeed also be feasible in mobile devices, and thus be one potential technology in, for example, 5G and beyond radio systems.

D. Kim, H. Lee, and D. Hong,

"A survey of in-band full-duplex transmission: from the perspective of PHY and MAC layers"

In-band full-duplex (IBFD) transmission represents an attractive option for increasing the throughput of wireless communication systems. A key challenge for IBFD transmission is reducing self-interference. Fortunately, the power associated with residual self-interference can be effectively canceled for feasible IBFD transmission with combinations of various advanced passive, analog, and digital self-interference cancellation schemes. In this survey paper, we first review the basic concepts of IBFD transmission with shared and separated antennas and advanced self-interference cancellation schemes. Furthermore, we also discuss the effects of IBFD transmission on system performance in various networks such as bidirectional, relay, and cellular topology networks. This survey covers a wide array of technologies that have been proposed in the literature as feasible for IBFD transmission and evaluates the performance of the IBFD systems compared to conventional half-duplex transmission in connection with theoretical aspects such as the achievable sum rate, network capacity, system reliability, and so on. We also discuss the research challenges and opportunities associated with the design and analysis of IBFD systems in a variety of network topologies. This work also explores the development of MAC protocols for an IBFD system in both infrastructure-based and ad hoc networks. Finally, we conclude our survey by reviewing the advantages of IBFD transmission when applied for different purposes, such as spectrum sensing, network secrecy, and wireless power transfer.

T. Huusari, Y. S. Choi, P. Liikkanen, D. Korpi, S. Talwar, and M. Valkama,

"Wideband self-adaptive RF cancellation circuit for full-duplex radio: operating principle and measurements,"

This paper presents a novel RF circuit architecture for self-interference cancellation in inband full-duplex radio transceivers. The developed canceller is able to provide wideband cancellation with waveform bandwidths in the order of 100 MHz or beyond and contains also self-adaptive or self-healing features enabling automatic tracking of time-varying self-interference channel characteristics. In addition to architecture and operating principle descriptions, we also provide actual RF measurements at 2.4 GHz ISM band demonstrating the achievable cancellation levels with different bandwidths and when operating in different antenna configurations and under low-cost highly nonlinear power amplifier. In a very challenging example with a 100 MHz waveform bandwidth, around 41 dB total cancellation is obtained while the corresponding cancellation figure is close to 60 dB with the more conventional 20 MHz carrier bandwidth. Also, efficient tracking in time-varying reflection scenarios is demonstrated.

M. Duarte and A. Sabharwal,

"Full-duplex wireless communications using off-the-shelf radios: feasibility and first results,"

We study full-duplex wireless communication systems where same band simultaneous bidirectional communication is achieved via cancellation of the self-interfering signal. Using off-the-shelf MIMO radios, we present experimental results that characterize the suppression performance of three self-interference cancellation mechanisms, which combine a different mix of analog and digital cancellation. Our experimental results show that while the amount of self-interference increases linearly with the transmitted power, the self-interference can be sufficiently cancelled to make full-duplex wireless communication feasible in many cases. Our experimental results further show that if the self-interference is cancelled in the analog domain before the interfering signal reaches the receiver front end, then the resulting full-duplex system can achieve rates higher than the rates achieved by a half-duplex system with identical analog resources.

M. Mohammadi, H. A. Suraweera, Y. Cao, I. Krikidis, and C. Tellambura,

"Full-duplex radio for uplink/downlink wireless access with spatially random nodes,"

A full-duplex (FD) multiple antenna access point (AP) communicating with single antenna half-duplex (HD) spatially random users to support simultaneous uplink (UL)/downlink (DL) transmissions is investigated. Since FD nodes are inherently constrained by the loopback interference (LI), we study precoding schemes for the AP based on maximum ratio combining (MRC)/maximal ratio transmission (MRT), zero-forcing, and the optimal scheme for UL and DL sum rate maximization using tools from stochastic geometry. In order to shed insights into the systems performance, simple expressions for single antenna/perfect LI cancellation/negligible internode interference cases are also presented. We show that FD precoding at AP improves the UL/DL sum rate and hence a doubling of the performance of the HD mode is achievable. In particular, our results show that these impressive performance gains remain substantially intact even if the LI cancellation is imperfect. Furthermore, relative performance gap between FD and HD modes increases as the number of transmit/receive antennas becomes large, while with the MRC/MRT scheme, increasing the receive antenna number at FD AP, is more beneficial in terms of sum rate than increasing the transmit antenna number.

V. PROPOSED WORK

- A two-fold RTS/CTS mechanism is proposed to coordinate the FD transmission while considering the impact of the IUI. An optimization problem is formulated in the second-fold contention to maximize its efficiency.
- A probability based hybrid mechanism is proposed, in which the AP is able to decide the probability of constructing FD transmission. Optimization problems are formulated in determining the probability to maximize the spectral efficiency.
- Simulation results show that the designed protocol significantly outperforms the HD MAC protocol and pervious DCF-based FD MAC protocols in terms of throughput. Moreover, the hybrid mechanism can provide performance gain to satisfy different system requirements in terms of UL/DL throughput.

VI. METHODOLOGY

External RTS/CTS Handshake

The goal of the external RTS/CTS handshake is to resolve the external contention and to construct the primary transmission. The handshake can be divided into two processes, i.e., the access contention process and the frame transmission process

Access contention process: All the users and the AP who tend to send a frame keep sensing the channel continuously. Once the channel is sensed idle without interruption for a distributed inter-frame space (DIFS), a random backoff time will be generated by each of them for additional deferral

Frame transmission process: When the channel is accessed successfully, the external RTS/CTS handshake process can be divided into two cases, featured by whether a user or the AP accesses the channel. If a user or the AP wins the external contention and accesses the channel, we refer to it as the UL-primary case or DL-primary case, respectively.

Internal RTS/CTS Handshake

After the external handshake, suppose there are NIn capable users to contend in the internal contention. All of them contend to get access to the channel by sending FD-RTS within the internal contention period. Similar to the external RTS/CTS handshake, the internal RTS/CTS handshake can be divided into two processes, i.e., the access contention process and the frame transmission process.

Simultaneous DATA Transmission

After the primary and secondary transmissions have been constructed, the simultaneous DATA transmission stage begins. The challenge in this stage is to coordinate the two parallel transmissions, i.e., when to begin transmitting DATA frames, when to reply ACKs, and when to expect ACKs to come. As both of the transmissions proceed in one channel, dis-coordination leads to interference between frames and result in failure.

UL/DL Rate and System Throughput

To calculate UL/DL rate and the system throughput, the access probability in external contention needs to be calculated first. Define the external state transit slot as a slot at the beginning of which users and the AP choose their states in the external contention stage, i.e., to begin transmitting or to keep sensing. The duration of an external state transit slot depends on the operation the users and the AP proceed in that slot. It can be as short as a time slot δ when all of the users and the AP are during their backoff processes, or as long as the duration of a whole transmission process from the beginning of RTS to the end of DIFS following ACK.

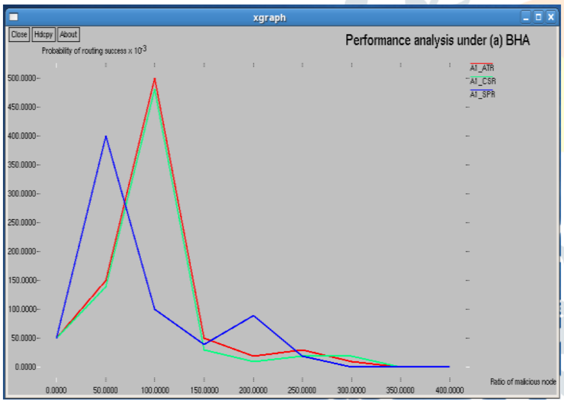
UL/DL Rate Optimization

As different kinds of services have distinct traffic demands, the wireless networks usually have different requirements on the UL and DL rates. Therefore, in order to give an insight on the promotion limit of the FD capability on UL/DL, we analyze the cases in which the FD capability is adopted to improve the UL/DL rate respectively.

VII. SIMULATION ENVIRONMENT

The experiment was conducted using NS2 running on a personal computer (PC).

Simulation Results



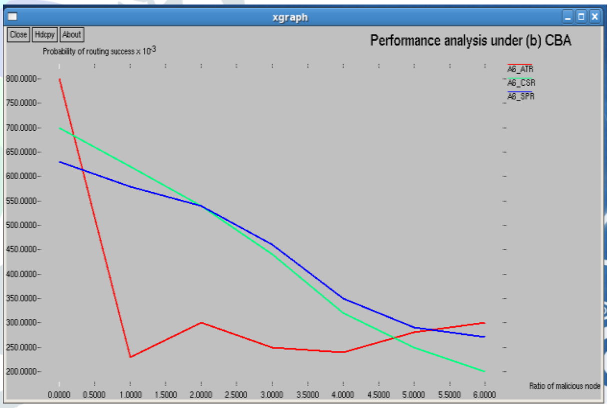


Fig. Performance analysis based on BHA and CBA

VIII. CONCLUSION

In this paper we examine the characteristics of the WSN. We discussed various type of energy efficient MAC protocol of WSN which is prominence on the energy efficiency; it is a critical issue for WSN. Because sensor nodes are hold batteries for control power in network. For application in WSN, reduction in energy consumption is essential, and the MAC protocol in WSN is the most important influential aspect in WSN energy performance. So the key problem is designing an energy efficient MAC protocol. One of the causes behind is the MAC protocol selection resolve, in a wide-ranging, application-dependent. This will give result that there is no standard protocol which give better energy efficiency. Hence enhances the scope of further research to design and develop more energy efficient protocols to satisfy their WSN application requirements and usages. A hybrid MAC protocol with a two-fold contention resolution mechanism was proposed to exploit the channel access opportunities in FD Wi-Fi networks while managing the IUI. We adopted a two-fold RTS/CTS contention resolution mechanism to construct the simultaneous UL and DL transmissions, and redesigned the structures of the control frames to enable the necessary information collection. To improve the performance of the protocol, an integer optimization problem was formulated to optimize the efficiency of the second-fold of RTS/CTS contention. In the protocol, the AP can decide whether to construct FD transmissions based on probability, which provides the networks with large flexibility to satisfy different system requirements. Specifically, three typical requirements were considered, i.e., maximizing the UL rate, the DL rate and the total system throughput.

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